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Scanning Mobility Particle Sizer: Fast data Inversion and uncertainty analysis

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Introduction

SMPS (Scanning Mobility Particle Sizer) is the most widely used device to characterize particle sizes below 0.1 µm and it takes part in a large range of applications such as toxicology testing, indoor air quality measurement, etc.

Yet, a dimensional uncertainty on the size distribution isn't provided to SMPS users when the instrument operates under scanning mode. Since it has been proved that ultra-fine particles can pass through human barriers (lung, blood-brain barrier, etc.), assessing uncertainties on the estimated size distribution has become of primary interest. Present study aims at simulating SMPS measurements and at proposing a fast and accurate inversion technique to estimate the particle size distribution, as well as providing a sensitivity analysis to determine the influent parameters of the system. A 95% confidence region on the output size distribution is finally obtained by performing Monte-Carlo simulations.

Model and Inversion

Aerosol measurement using a SMPS is based on particle electrical mobility, that is defined as the ratio of the particles drift velocity to the magnitude of the electric field; particle electrical mobility is then linked to its mobility diameter d_p and electrical charge p. Once selected by DMA (Differential Mobility Analyser), particles are gathered into canals, enlarged and detected by a CPC (Condensation Particle Counter). Wang and Flagan (1990) developed the theory of particle classification when the instrument operates under scanning mode, and precision on the voltage ramp is given by Collins *et al.* (2004).

Raw data extracted from the SMPS represent a concentration over a certain class of mobility diameters. If we denote r_i as the concentration over the class i, n the size distribution, p the number of charges carried by a particle, $d_{1,i}$ and $d_{2,i}$ respectively the left and right extremity of the class i, t_i the counting time for the class i, $t_{0,i}$ being the time at which the count begins in the class i, f describes particle electrical mobility selected according to scanning time and k_i the kernel function (product of the charge distribution, the detection efficiency of the CPC, the DMA transfer function), then:

$$r_i = \frac{1}{t_{0,i}} \cdot \iint_{\left[d_{1,i},d_{2,i}\right]\times\left[t_i,t_i+t_{0,i}\right]} k_i\left(f(t),p,d_p\right)\cdot n(d_p)\cdot dd_p \times dt .$$

Starting from the deterministic model, next step is to focus on the variability of the measurements. Indeed, a model of noise based on experimental results that takes into account the CPC counting modes (single particle counting, live-time counting and photometric mode) is created.

Knowing the concentrations for each class, data inversion consists in retrieving the size distribution. It is a minimization problem with the constraint of positivity of the solution. Regularization technique of Tikhonov and Arsenin (1977) that penalizes non-smooth solutions is performed. In our case, the inversion has been proved to be fast and stable to perturbations in the input space and can then be used for the sensitivity analysis.

Primary Results

Since the number of parameters involved in the model is high, sensitivity analysis would require too much computing time, that's why analysis based on the decomposition of the variance is carried out by using indices defined by Sobol (1993). Then, according to experts in aerosol physics, the range of variation for each influent parameter of the system is chosen and a 95 % confidence interval is computed using Monte-Carlo simulations as shown in figure 1 for a typical atmospheric aerosol size distribution (Whitby, 1978).

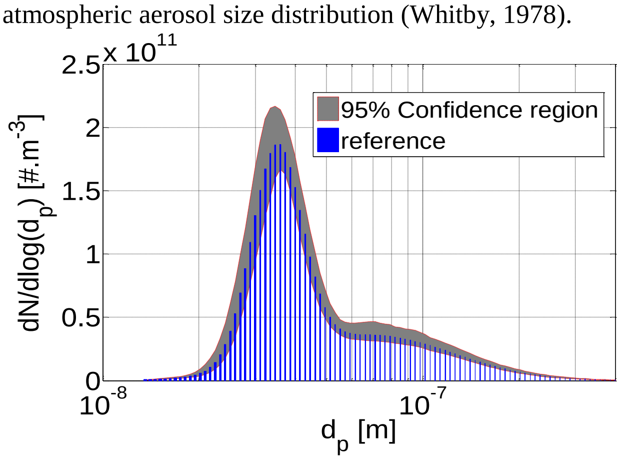

Figure 1. 95% confidence region when simulating SMPS measurement of an atmospheric aerosol

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